LCA Methodology

Distance-to-Target Weighting in Life Cycle Impact Assessment Based on Chinese Environmental Policy for the Period 1995–2005

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Abstract

Background and Objectives. Values in the known weighting methods in Life Cycle Assessment are mostly founded by the societal systems of developed countries. What source of weights and which weighting methods are reliable for a big developing country like China? The purpose of this paper is to find a possible weighting method and available data that will work well for LCA practices conducted in China. Since government policies and decisions play a leading role in the process of environmental protection in developing countries, the weights derived from political statements may be a consensus by representatives of the public.

Methods. 'Distance-to-political target' principle is used in this paper to derive weights of five problem-oriented impact categories. The critical policy targets are deduced from the environmental policies issued in the period of the Ninth Five-year (1996–2000) and the Tenth Five-year (2001–2005) Plan for the Development of National Economy and Society of China. Policy targets on two five-year periods are presented and analyzed. Weights are determined by the quotient between the reference levels and target levels of a certain impact category.

Results and Discussion. Since the Tenth Five-year Plan put forward the overall objective to reduce the level of regional pollution by 2005, the weights for AP, EP and POCP for 2000–2005 are more than 1. By comparison between the Ninth Five-year and Tenth Five-year period, the results show that the weights obtained in this paper effectively represent Chinese political environmental priorities in different periods.

For the weights derived from China's political targets for the overall period 1995–2005, the rank order of relative importance is ODP>AP>POCP>EP>GWP. They are recommended to the potential users for the broader disparity among the five categories. By comparison with the weights presented by the widespread EDIP method, the result shows that there's a big difference in the relative importance of ozone depletion and global warming.

Conclusion. The weighting factors and rank order of impact categories determined in this study represent the characteristics of the big developing country. The derived weighting set can be helpful to LCA practices of products within the industrial systems of China.

Keywords: Distance-to-target; weighting; environmental policy; China; life cycle impact assessment (LCIA)

Introduction

The question of weighting in Life Cycle Assessment arises when trade-offs of different kinds of environmental disturbances are involved. Weighting inherently uses values and subjectivity to derive a rank order, and then possibly support the aggregation of the indicator results across impact categories into a final score.

Several weighting methods in LCA have been developed during the 1990s and these are currently being used. SETAC workgroup on LCIA distinguished types of weighting as [1]:

- monetary methods, such as society's willingness to pay, shadow costs, etc.,
- sustainability and target methods, such as in the distance-to-target procedure, and
- social and expert methods.

These weighting methods differ in many respects and may in specific case studies lead to different results [2]. SETAC workshop on LCIA has considered the construction of a generic weighting set to be used in different studies. Vividly, however, there has been a lot of debate as to if and how to derive one generic weighting set [3–4].

Values in the available weighting methods are mostly founded by the societal systems of developed countries. A question posed is therefore: What source of weights and which weighting methods are reliable for a big developing country like China?

Lack of individual, environmental sensitivity and LCA expertise in China is a major obstacle to both monetary and panel methods. Government policies and actions of developing countries play a leading role in the process of their environmental protection. Therefore, the weights derived from political statements in the distance-to-target procedure may be a consensus by the representatives of the public, to some extent, in the big developing country.

The 'distance-to-political target' weighting principle has been used in the widely applied LCA methods of Swiss Ecoscarcity [5] and Denmark EDIP [6] during the 1990s. A criticism raised against distance-to-target methods based on policy goals is that political targets may be of different dignity and no inter-effect weighting is made [7–8]. If, however, goal conflicts have been discussed explicitly in the policy making process, the critique is less valid.

Yang JX (1999) [9] also tried the distance-to-target method based on China's policy for the period 1990–2000. Since Chinese environmental policy was made in a general way in the early 1990s, most targets in Yang's research are rough estimations rather than political goals.

This study attempt to construct distance-to-target weighting systems based on the environmental policies issued in the period of the Ninth Five-year (1996–2000) and the Tenth Five-year (2001–2005) Plan for the Development of National Economy and Society of China. In this period, policy making is discussed by the advisory panels of experts and formulated in a very specific manner by setting targets for emission flows or for background concentrations to be met. Different from Yang's research, a new analytical method of policy targets and a new set of data are both adopted in this study. In order to illustrate the evolvement of environmental protection in China, policy targets on two Five-year periods are presented and analysed. The weights based on the five-year political interval are quantified and compared. In addition, the weighting set based on the overall ten-year interval (1995–2005) is compared with the EDIP method for a better understanding of the characteristics of the big developing country.

1 Methodology

'Distance-to-political target' weighting principles are used in this paper to derive weights of five problem-oriented impact categories: ozone depletion, global warming, acidification, eutrophication and photochemical smog. The characterization models linking emission flows and their potential impacts are based on the available references [10–15].

The underlying principle of distance-to-target is simple: the quotient between the reference levels of impact potential and the target level indicates how important a certain category of impact is considered in the political area. A contribution to the overall flow of a certain impact, where the reference levels of contributors are far above the target level, is thus given more weight than contributions to flows where the distance-to-target is smaller.

Amount control targets of national pollutant discharge are adopted in this study. Since China is the world's most populous country, China's per capita emissions are generally less than the per head average of industrialized countries or the world. That's why the Chinese government implements the amount control targets, rather than per capita reduction targets.

In order to deduce the critical targets, policy analysis is conducted carefully step-by-step from the international protocols, the national plans or regulations, to the quantitative targets. If the overall qualitative targets are only set in the official documents, the emissions are estimated based on the overall qualitative targets and the available literature. The targets are calculated by the division between the reference level and the target level.

2 Policy Analysis and Weight Determination

2.1 Ozone Depletion Potential (ODP)

China ratified the Montreal Protocol (London Amendment) on Substances that Deplete the Ozone Layer in 1991. Control measures under the Article 5 (1) parties of the Montreal Protocol are applicable to China. China has compiled the National Programme for the Phasing out of Substances Depleting the Ozone Layer [16] as part of its implementation of the Montreal protocol. Therefore, the weights for Ozone Depletion are derived from the quotient between the consumption levels and targets of ODS under the National Programme. **Table 1** briefly presents the reduction targets and inventory results for ozone depletion.

Table 1: Reduction targets, calculated impact potential in ODP tones and weights for Ozone Depletion in 1995–2005

Substance	China, 1995	Reduction target, 1995–2000	China, 2000	Reduction target, 2000–2005	China, 2005	Reduction target, 1995–2005
	ODP: CFC-11 eq.		ODP : CFC-11 eq.		ODP : CFC-11 eq.	
CFC-11	2.97E+04	23.0%	2.29E+04	54.7%	1.03E+04	65.1%
CFC-12	3.00E+04	47.6%	1.57E+04	60.3%	6.22E+03	79.2%
CFC-113	3.30E+03	–39.9%	4.61E+03	86.6%	6.19E+02	81.2%
CFC-114 & 115	8.00E+01	–71.3%	1.37E+02	45.0%	7.53E+01	5.9%
Halon-1211	5.58E+04	50.9%	2.74E+04	64.8%	9.64E+03	82.7%
Halon-1301	2.28E+03	–57.9%	3.60E+03	50.0%	1.80E+03	21.1%
CFC-13	1.36E+02	48.5%	7.00E+01	28.6%	5.00E+01	63.2%
carbon tetrachloride	5.05E+02	78.2%	1.10E+02	100.0%	0.00E+00	100.0%
1,1,1-trichloroethane	5.42E+02	–50.3%	8.15E+02	29.9%	5.71E+02	–5.3%
Total	1.22E+05	38.4%	7.53E+04	61.0%	2.93E+04	76.0%
Weights (ozone depletion)		**1.62**		**2.57**		**4.17**

2.2 Global Warming Potential (GWP)

The Chinese government has ratified the Kyoto Protocol. There are no specific reduction targets for CO_2 emission at present, however, since the Chinese government is making an effort to control the total energy consumption and increase the composition of cleaner energy as part of its implementation of the Kyoto Protocol. The industrial activity in China has been developing significantly over these years. More effort is put into the decrease of elasticity ratio of energy consumption, which indicates the quotient between the growth rates of energy consumption and Gross Domestic Product (GDP).

The estimation of CO_2 emissions from fuel combustion in this study are based on the energy consumption and emission factors by fuel type [17]. Energy consumption for the year 1995 and 2000 is extracted from the China Statistical Yearbook (2003). For the target year 2005, energy estimation is based on the growth rate of gross domestic product (7% per year) and elasticity ratio of energy consumption (0.4) set in the Tenth Five-year Plan.

CO_2 emissions from other sources and CH_4 emissions are calculated from the baseline emission scenario developed by the China Climate Change Country Study [17].

In addition, all the ozone depletion substances presented in Table 1 are also taken as greenhouse gases in this section. **Table 2** provides the reduction targets and inventory results for global warming.

2.3 Acidification Potential (AP)

The contribution of sulfur dioxide and nitrogen oxides to acidification in China is discussed in this section.

Both the National Ninth Five- year Plan [18] and Tenth Five-year Plan [19] for Environmental Protection bring forward the control indices for national emission flows of sulfur dioxide. According to the Ninth Five-year Plan, efforts should be made to basically bring the worsening trend of environmental pollution under control. By the year 2000, the national emission of SO_2 will therefore only increase by 3.8% relative to the 1995 level. More stringently, however, the Tenth Five-year Plan set a 10.0% reduction target to promote the control of acid rain. In ten years, the annual emission flows of SO_2 in 2005 will be reduced by 24.1% relative to the 1995 level.

There's no specific political target for the emission of NO_x. NO_x emission estimates is based on energy consumption estimates discussed in the GWP section and emission factors from the corresponding references [20–21]. **Table 3** shows the reduction targets and inventory results for acidification.

Table 2: Reduction targets, impact potential in GWP tones and weights for global warming in 1995–2005

Substance	China, 1995	Reduction target, 1995–2000	China, 2000	Reduction target, 2000–2005	China, 2005	Reduction target, 1995–2005
	GWP: CO_2 eq.		GWP: CO_2 eq.		GWP: CO_2 eq.	
CO_2	2.54E+09	2.6%	2.47E+09	–9.7%	2.71E+09	–6.9%
CH_4	8.96E+08	–14.8%	1.03E+09	–13.0%	1.16E+09	–29.7%
CFC-11	1.37E+08	23.0%	1.05E+08	54.7%	4.76E+07	65.1%
CFC-12	3.87E+08	47.6%	2.03E+08	60.3%	8.05E+07	79.2%
CFC-113	2.20E+07	–39.9%	3.08E+07	86.6%	4.13E+06	81.2%
CFC-114 & CFC-115	8.35E+05	–175.9%	2.30E+06	44.7%	1.27E+06	–52.6%
Halon-1211	1.42E+07	50.9%	6.98E+06	64.8%	2.46E+06	82.7%
Halon-1301	1.31E+06	–57.9%	2.07E+06	50.0%	1.04E+06	21.1%
CFC-13	1.90E+06	48.5%	9.80E+05	28.6%	7.00E+05	63.2%
Carbon tetrachloride	8.26E+05	78.2%	1.80E+05	100.0%	0.00E+00	100.0%
1,1,1-trichloroethane	6.90E+05	–50.3%	1.04E+06	29.9%	7.26E+05	–5.3%
Total	4.00E+09	3.7%	3.85E+09	–4.1%	4.01E+09	–0.3%
Weights (global warming)		**1.04**		**0.96**		**1.00**

Table 3: Reduction targets, calculated impact potential in AP tones and weighting values for acidification in 1995–2005

Substance	Ninth Five-year Plan			Tenth Five-year Plan			Reduction target, 1995–2005
	1995	Reduction target, 1995–2000	2000 [a)]	2000 [b)]	Reduction target, 2000–2005	2005	
	AP: SO_2 eq.		AP: SO_2 eq.	AP: SO_2 eq.		AP: SO_2 eq.	
SO_2	2.37E+07	–3.8%	2.46E+07	2.00E+07	10.0%	1.80E+07	24.1%
NO_x	5.65E+06	1.56%	5.56E+06	5.56E+06	–6.8%	5.94E+06	–5.1%
Total	3.41E+07	–2.91%	3.51E+07	2.96E+07	6.8%	2.75E+07	19.2%
Weights (acidification)		**0.97**			**1.07**		**1.24**

For SO_2: a) Data planned in the ninth five-year plan
b) Actual data in the tenth five-year plan

2.4 Eutrophication Potential (EP)

The waterborne emission of COD, Ammonia Nitrogen and Total Phosphorus, and airborne emission of nitrogen oxides are taken into account in this section of eutrophication. The emission levels and targets are based on the National Ninth Five-year (1995–2000) and Tenth Five-year Plan (2000–2005) for Environmental Protection [18–19].

The Ninth Five-year Plan set the reduction target only for COD release. In 2000, the total COD release should be reduced by 1.5% relative to that in 1995. In the Tenth Five-year Plan, however, both of the reduction targets for the COD and Ammonia Nitrogen release are set at nearly 10.0%. In ten years, the reduction target for annual emissions will arrive at 41.8% for COD and 6.7% for ammonia nitrogen and total phosphorus.

There are no official data or research data available for aquatic emissions of ammonia nitrogen in the year 1995. The official data in the year 2000 is 778,400 tons from industrial wastewater, and 1,056,600 tons from domestic wastewater. There are no specific control targets for ammonia nitrogen in 1995–2000. Therefore, a rough estimation for 1995 is made based on the amount of industrial and domestic wastewater discharged, and their contents of ammonia nitrogen according to the data in the year 2000.

The airborne emissions of NO_x have been presented in section 2.3.

Table 4 provides the reduction targets and inventory results for eutrophication.

2.5 Photochemical Ozone Creation Potential (POCP)

Photochemical smog pollution in China mostly occurs in the areas of the petrochemical industry, and in the big cities with a large population of vehicles. Chinese environmental policy for photochemical smog pollution is formulated by setting targets for background concentrations to be met (quality standards) and emissions standards of automobile exhaust. Therefore, this section will discuss and estimate national emission flows of CO, NO_x and HC emissions from automobile running, petroleum-refining and fuel combustion.

As the vehicle population of the country is rapidly increasing, the air pollution in China's medium and big cities (typical of Beijing, Guangzhou and Shanghai) is in a transition from coal burning-caused problems to automobile exhaust-related pollution. The State Environmental Protection Administration (SEPA) of China has released the national technical policies for mobile-source pollution prevention and control [22] in recent years. The overall target is to arrive at Euro I equivalent emission levels by the year 2000 and Euro II equivalent emission levels by the year 2005. This target represents a large reduction of mobile-source emissions. Emission mass flows of CO and HC from mobile exhaust are computed in the model using **Eq. 1**.

$$\text{Emissions per Year[g]} = \text{Emission Factor [g/km]} * \text{Number of Vehicles [veh.]} * \text{Mileage per Vehicle per Year [km/veh.]} \quad (1)$$

National mobile-source emission flows in 1995 are extracted from Li Wei and Fu Lixin et al. (2003) [23]. Emission factors for vehicles in the target year 2000 and 2005 are calculated on the basis of the reductions brought in the emission factors of pre-control vehicles. It is assumed that the reduction factor for any pollutant is equal to the ratio of the respective emission standards over the pre-control referent standards [24–29]. In addition, future vehicle population is predicted based on the National Five-year Plan on Automobile Industry [30] and Wang Jinnan et al. (2000) [31].

As mentioned at the beginning of this section, the areas of the petrochemical industry in China also have a high risk of photochemical smog pollution. Fugitive emission flows of hydrocarbon from the oil refining industry are calculated by multiplying the national output of crude oil by the rate of processing loss.

the national output of crude oil and the average rate of processing loss in the period 1995–2005 are based on related national statistics and scientific assumptions. According to the Tenth Five-Year Plan for the Petrochemical Industry [32], the average rate of processing loss will decrease slightly due to the improved technological level, nevertheless, the output of crude oil is obviously on the rise for the increasing demand of oil products with the continuing development of the national economy. Therefore, the overall emission of non-methane hydrocarbon from petroleum refining industry will go up in 1995–2000.

Table 4: Reduction targets, calculated impact potential in EP tones and weights for eutrophication in 1995–2005

Substance	Ninth Five-year Plan			Tenth Five-year Plan			Reduction target, 1995–2005
	1995	Reduction target, 1995–2000	2000 a)	2000 b)	Reduction target, 2000–2005	2005	
	EP: NO_3^- eq.		EP: NO_3^- eq.	EP: NO_3^- eq.		EP: NO_3^- eq.	
COD	5.14E+06	1.5%	5.06E+06	3.32E+06	10.0%	2.99E+06	41.8%
Total Phosphorus	2.83E+06	–3.8%	2.94E+06	2.94E+06	10.1%	2.64E+06	6.7%
Ammonia Nitrogen	6.08E+06	–3.8%	6.31E+06	6.31E+06	10.1%	5.68E+06	6.7%
NO_x	1.53E+07	1.6%	1.50E+07	1.50E+07	–6.8%	1.60E+07	–5.1%
Total	2.93E+07	–0.1%	2.93E+07	2.76E+07	0.9%	2.73E+07	6.7%
Weights (eutrophication)		**1.00**			**1.01**		**1.07**

For COD: a) Data planned in the ninth five-year plan
b) Actual data in the tenth five-year plan

Table 5: Reduction targets, calculated impact potential in POCP tones and weights for photochemical smog

Substance	Source category	1995 POCP: C_2H_4 eq.	Reduction target, 1995–2000	2000 POCP: C_2H_4 eq.	Reduction target, 2000–2005	2005 POCP: C_2H_4 eq.	Reduction target, 1995–2005
HC	mobile	2.03E+06	–11.0%	2.25E+06	43.7%	1.27E+06	37.5%
	oil refining	1.29E+06	24.1%	1.60E+06	–5.1%	1.68E+06	–30.5%
	Fuel combustion	1.04E+05	3.0%	1.01E+05	–11.4%	1.13E+05	–8.0%
CO	mobile	4.81E+05	15.6%	4.06E+05	28.2%	2.91E+05	39.4%
	Fuel combustion	7.25E+04	9.8%	6.54E+04	–7.4%	7.03E+04	3.1%
NO_x	Fuel combustion	3.16E+05	1.6%	3.11E+05	–6.8%	3.32E+05	–5.1%
Total		4.29E+06	–10.4%	4.74E+06	20.7%	3.76E+06	12.5%
Weights (photochemical smog)			**0.91**		**1.26**		**1.14**

Table 5 provides the reduction target and inventory results for photochemical smog.

3 Results and Discussion

The 'distance-to-political target' weighting factors by this work by Yang JX (1999) and the EDIP method are summarized in **Table 6.**

In a comparison between the ninth five-year and tenth five-year period, the results show that the weights obtained in this paper effectively represent Chinese political and environmental priorities in different periods. Since the Tenth Five-year Plan put forward the overall objective to reduce the level of regional pollution by 2005, the weights for AP, EP and POCP for 2000–2005 is more than 1. In addition, it is interesting to note that the value for POCP in 2000–2005 is slightly higher than for AP and EP. This indicates that the policy for mobile-source pollution prevention and control is stringent and highly tightened with the worsening trend of mobile-source pollution.

For the distance-to-target factors derived in this study for the overall period 1995–2005, the highest value of AP among the three regional impact categories is in accordance with the severe acidification problem in China. In addition, the disparity among the five categories is broader. Therefore, the weighting factors for the overall period 1995–2005 are recommended to the potential users.

Compared with the EDIP method based on the global and Danish per capita reduction targets, the leading role of ozone depletion among the China-based weights for the overall period 1995–2005 doesn't change. Nevertheless, the relative importance to the other impact categories decreases. A difference up to sixfold is found. This is partly due to the lower reduction obligation of China under the Montreal Protocol. Moreover, note that the China-based value for global warming is nearly 1. This reality is also quite different from that in the industrialized nations – the so-called Annex 1 countries, where the Kyoto Protocol called to reduce their average national emissions over the period 2008–2012 to about 5% below 1990 levels. None of the developing countries was required to set any limits.

The big differences in global warming and ozone depletion indicate that the Western industrialized countries are focus more on global issues of great future significance. The developing countries like China are hardest hit by local and regional problems, thus having more concern for photochemical smog, acid rain and malnutrition.

Table 6: 'Distance-to-political target' factors determined by this study and the related references

Impact Category	This study			Yang JX(1999)	EDIP [4]
	China	China	China	China	The world / Denmark
	Ninth Five-year Plan 1995–2000	Tenth Five-year Plan 2000–2005	Ninth & Tenth Five-year Plan 1995–2005	1990–2000	1990–2000
ODP	1.62	2.57	4.17	2.7	23
GWP	1.04	0.96	1.00	0.83	1.3
AP	0.97	1.07	1.24	0.73	1.3
EP	1.00	1.01	1.07	0.73	1.2
POCP	0.91	1.26	1.14	0.51	1.2

4 Conclusions

'Distance-to-target' weighting factors of five midpoint impact categories based on Chinese environmental policy for the period 1995–2005 are determined in this study. The derived values and rank order of impact categories represent the characteristics of the big developing country. It may work well for the LCA practices of products within the industrial systems of China.

This study has made great efforts to establish or search for the available and appropriate data for use. However, some of them are still open questions left to the further work. More modeling has to be developed to ensure the link between the inventory table and policy targets when only background concentrations are regulated, i.e. the target ozone concentration. The weights will update with the tightened policy and new, available data in the future. More categories will be taken into account.

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